Absolute Time Calibration for the Chandra X-ray Observatory

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Abstract

We performed an absolute time calibration of the Chandra clock through simultaneous observations by Chandra and the Rossi X-ray Timing Explorer (RXTE) of the millisecond pulsar PSR B1821-24. Using an updated clock correlation file, we find that the error in the Chandra clock, with respect to the RXTE clock, is 4±3 μs. Considering that the uncertainty in the RXTE times is typically 2 μs and taking into account other sources of error, we conclude that Chandra time is off by 4±4 μs. We add two caveats to this. First, this is only a single snapshot measurement; although we feel confident about the stability of the Chandra clock, we cannot entirely exclude the possibility of random or systematic variations in this offset. Second, first-version standard production data are typically run by CXC with an extrapolated clock correlation; in this particular case the error in the extrapolated clock correlation was 3±1 μs, but that is not necessarily a typical value. The final conclusion is that with careful processing we may reasonably have confidence that Chandra absolute time can achieve an accuracy of 4 μs.

Introduction

An accurate absolute time calibration of the Chandra X-ray Observatory is particularly important for observations made with the HRC in Timing Mode which affords a timing resolution of 16 μs. In 2003, the precision of the time stamps in Chandra data was improved considerably after Northrop-Grumman personnel associated with the Chandra FOT derived an instrumental correction of 284.4 μs (reported by W. S. Davis[1]) and A. H. Rots confirmed that this produced correct absolute times within about 50 μs, on the basis of observations of the Crab pulsar[2]; to be precise, the offset was determined to be 35±12 μs. However, the peak of the Crab pulse is sufficiently wide to preclude a very accurate timing determination and in retrospect we must conclude that the error was underestimated. Nevertheless, this result yielded an order of magnitude improvement in the precision of the Chandra time stamps.

What is needed for a precise measurement of the absolute clock error, allowing another order of magnitude improvement, is a celestial observation of a pulse that can be timed accurately and that has a width of no more than a few tens of μs. This can be achieved by simultaneous observations with Chandra and the Rossi X-ray Timing Explorer (RXTE) of the millisecond pulsar PSR B1821-24 which has a very sharp component in its X-ray pulse profile.

Observations and Analysis

The 3 millisecond pulsar PSR B1821-24 was observed on 27 May 2006 for 41 ks by Chandra (HRC timing mode) and for 16 ks by RXTE (GoodXenon event mode). The time range of the RXTE observation was fully covered by the Chandra observation. Chandra data are routinely processed with only past clock correlation information, extrapolated to the date of observation. This Chandra observation was reprocessed with a clock correlation file that was based on clock correlation data obtained before and after

[1] See http://cxc.harvard.edu/ccw/proceedings/03_proc/presentations/davis/
[2] See http://cxc.harvard.edu/ccw/proceedings/03_proc/presentations/rots/Clock.html

the observation. The RXTE time stamps can be corrected during analysis through the use of a fine-clock-correction file, tdc.dat.
Paul Demorest and Donald Backer (UC Berkeley) kindly provided us with an accurate timing ephemeris of the pulsar for this epoch, based on radio monitoring observations.
Both X-ray observations were analyzed using the program faseBin, that bins the individual events using orbit ephemeris, timing ephemeris, and clock corrections. The resulting pulse profiles are shown in Figs. 1 and 2. We have some doubts about the zero-phase point of the timing ephemeris, but since the ephemeris was applied to both observations any such term would vanish.

Results

The offset between the two pulse profiles was measured by cross-correlating the profiles and fitting a Lorentzian to the cross-correlation function. We conclude from this fit that the Chandra time stamps in the present observation are 4±3 μs too late.
We performed the same analysis comparing the standard Chandra data with the data derived from the improved clock correlation and found the difference to be 3±1 μs.

There are seven other sources of error:

RXTE orbit ephemeris	< 0.2 μs
RXTE timing calibration error	< 2 μs
Chandra orbit ephemeris	< 0.5 μs
Chandra random clock variations	unknown
Chandra relativistic orbital variations	< 1 μs
Chandra clock correlation error	1.8 μs
Chandra clock correlation extrapolation	12±12 μs (see text)

The large unknowns here are random variations in the Chandra clock that we know nothing about and the error resulting from the extrapolation of the clock correlation data. The latter can actually run anywhere from 3 to 25 μs, depending on the time elapsed since the last correlation used.
Our recommendation is to have observations that are very time-critical reprocessed using an improved clock correlation file; this is already the case for all observations performed prior to 15 November 2005. We also recommend that the CXC consider whether to adjust the present standard clock correction in Standard Data Processing from 284.4 to 280.4 μs. These recommendations should result in an absolute time accuracy of about 4 μs, unless there are random variations in the Chandra clock of the same order or larger. The only way to get a direct handle on that error is to repeat these coordinated observations several times. Absent such observations, one may infer from the dispersion of deviations between adjacent clock correlations (1.8 μs[3]) that such variations are likely to be smaller. Hence, we feel that, if these recommendations are followed, one may reasonably have confidence that the Chandra absolute time stamps are accurate to about 4 μs.

Acknowledgments

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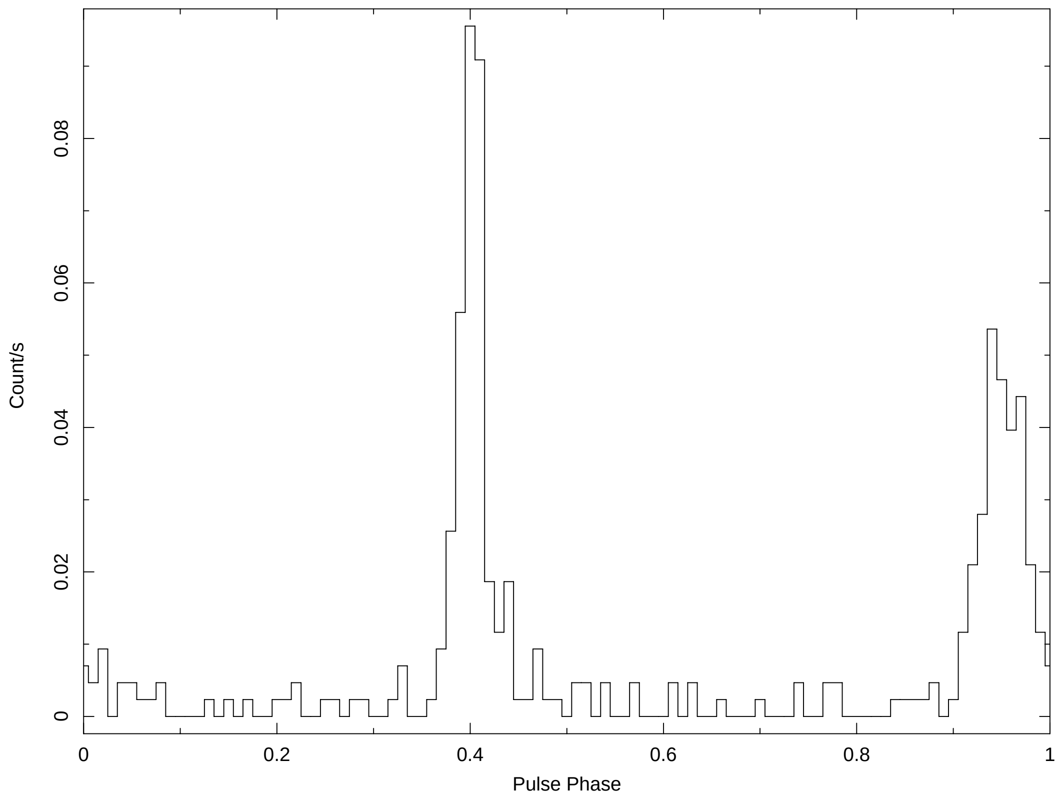
[3] I. Evans 2006, CXC-DS ECR 06-005

PSR B1821−24
Chandra/HRC 0.2−2 keV Pulse Profile



PSR B1821−24
RXTE/PCA 2−16 keV Pulse Profile